Associations between self-reported and objectively measured physical activity, sedentary behavior and overweight/obesity in NHANES 2003–2006

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Abstract: OBJECTIVE: To investigate associations between self-reported and objectively measured physical activity, sedentary behavior and overweight/obesity based on percent body fat measured with Dual Energy X-Ray Absorptiometry (DXA), waist circumference (WC), waist-to-height ratio and body mass index, focusing on different intensities and domains of physical activity. METHODS: Data from NHANES 2003-2006 were analyzed using linear and ordered logistic regression analyses. A total of 4794 individuals aged 18-69 years with valid physical activity and DXA data were included. Objectively measured physical activity and sedentary behavior were assessed using accelerometers, self-reported physical activity using the NHANES physical activity questionnaire. Weight, height, WC and DXA measures were assessed in the mobile examination centers. RESULTS: We observed statistically significant associations between objectively measured moderate and vigorous physical activity and all definitions of overweight/obesity. For total physical activity, the odds of being in the higher percent body fat category were 0.56 (95% confidence interval (CI) 0.41, 0.77) for the medium and 0.30 (95% CI 0.22, 0.40) for the highest physical activity tertile compared with the lowest. For light activities, lifestyle activities and sedentary behavior, associations were only observed in the linear models with percent total body fat but not in the ordered logistic regression models. Regarding self-reported physical activity, consistent significant associations with overweight/obesity were only observed for vigorous and for transport activity. CONCLUSIONS: Regarding moderate and vigorous physical activity, more active individuals were less affected by overweight/obesity than less active individuals, emphasizing the public health effect of physical activity in the prevention of overweight/obesity. The fact that associations were more consistent for objectively measured than for self-reported physical activity may be due to bias related to self-reporting. Associations between lower intensity activities and overweight/obesity were weak or inexistent.International Journal of Obesity advance online publication, 25 October 2016; doi:10.1038/ijo.2016.168.

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Title: Associations between self-reported and objectively measured physical activity, sedentary behavior and overweight/obesity in NHANES 2003-2006

Running title: Physical activity, sedentary behavior and obesity

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Conflict of interest

The authors declare no conflict of interest.

Abstract

Objectives

To investigate associations between self-reported and objectively measured physical activity, sedentary behavior and overweight/obesity based on percent body fat measured with Dual Energy X-Ray Absorptiometry (DXA), waist circumference (WC), waist-to-height ratio (WHtR) and body mass index (BMI), focusing on different intensities and domains of physical activity.

Methods

Data from NHANES 2003-2006 were analyzed using linear and ordered logistic regression analyses. A total of 4794 individuals aged 18-69 years with valid physical activity and DXA data were included. Objectively measured physical activity and sedentary behavior were assessed using accelerometers, self-reported physical activity using the NHANES physical activity questionnaire. Weight, height, WC and DXA measures were assessed in the mobile examination centers.

Results

We observed statistically significant associations between objectively measured moderate and vigorous physical activity and all definitions of overweight/obesity. For total physical activity, the odds of being in the higher percent body fat category were 0.56 (95% CI 0.41, 0.77) for the medium and 0.30 (95% CI 0.22, 0.40) for the highest physical activity tertile compared to the lowest. For light activities, lifestyle activities and sedentary behavior, associations were only observed in the linear models with percent total body fat but not in the ordered logistic regression models. Regarding self-reported physical activity, consistent significant associations with overweight/obesity were only observed for vigorous and for transport activity.

Conclusions

Regarding moderate and vigorous physical activity, more active individuals were less affected by overweight/obesity than less active individuals, emphasizing the public health effect of physical activity in the prevention of overweight/obesity. The fact that associations were more consistent for objectively measured than for self-reported physical activity may be due to bias related to self-reporting. Associations between lower intensity activities and overweight/obesity were weak or inexistent.

Introduction

Physical activity contributes up to 50% of total daily energy expenditure,[1] and there is evidence that active individuals have a healthier body weight and composition than inactive individuals.[2-4] To date, the majority of evidence on associations between physical activity, sedentary behavior and overweight/obesity has been derived from self-report measures, with body mass index (BMI) as most frequently used measure for the definition of overweight/obesity. However, there is controversy on whether BMI is appropriate for defining people at risk.[5] Measures of central obesity like waist circumference (WC),[6] waist-to-hip ratio (WHR)[6,7] and waist-to-height ratio (WHtR)[5] were better discriminators for morbidity and mortality risk. Moreover, Dual Energy X-Ray Absorptiometry (DXA) is considered a gold-standard measurement of body composition,[8] however, not many studies include such measures due to resource limitations.

Only few studies have investigated the association between objectively measured physical activity and sedentary behavior and overweight/obesity, mostly in small samples[9-11] and specific sub groups.[10,11] Some publications are available based on the Health Survey for England mostly regarding associations between sedentary behavior (both self-reported and accelerometer-derived)[12,13] but also physical activity[14] and cardiometabolic risk factors including BMI.

Earlier studies using NHANES data reported associations between objectively measured physical activity and overweight,[15] or both sedentary time and physical activity on overweight.[16,17]

Most evidence on associations between physical activity and weight status is available for leisure-time physical activity,[18] whereas less is known about the impact of other domains of physical activity. Furthermore, to our knowledge, there is no study including both objective measures of physical activity and sedentary behavior and percent body fat based on DXA measurements.

The National Health and Nutrition Examination Survey (NHANES) 2003-06 provides information on objectively measured (accelerometers) and self-reported (questionnaire) physical activity as well as various measures of body composition. The aim of this study was to investigate cross-sectional associations between self-reported and objectively measured physical activity and sedentary behavior on the one hand and different anthropometric measures and derived overweight/obesity definitions on

the other hand. Regarding physical activity, we focused on different intensities (light, lifestyle, moderate and vigorous) and different domains (leisure-time, transport, household).

Materials and Methods

Sample

We used data from NHANES 2003-2006, representative of the US civilian non-institutionalized population. A multistage probability sampling was used to recruit participants. The NCHS Institutional Review Board has reviewed and approved the study protocol and all participants gave written informed consent.[19]

We considered 9173 individuals aged 18-69 years (DXA was only measured in individuals aged ≤69 years). Of these, we excluded 390 individuals because they only participated in the interview, 694 because of missing DXA data and 416 due to missing data on dietary intake (N=7673). Furthermore, 2801 individuals were excluded because they had not sufficient valid objectively measured physical activity data and two individuals due to missing self-reported physical activity data (N=4870). Finally, 76 individuals were excluded because they were categorized as underweight, leaving 4794 individuals for analyses. For sensitivity analyses, we repeated the analyses for self-reported physical activity without excluding individuals that had missing objectively measured physical activity.

Measures

Physical activity

Physical activity was assessed objectively in 2003/04 and 2005/06 using the validated ActiGraph 7164 accelerometer (ActiGraph, Shalimar, FL).[20] The participants were instructed to wear an accelerometer placed on their right hip for 7 consecutive days following the examination at the medical examination center (MEC). The chosen epoch time was 1 minute. Inclusion criteria for the present analyses were: ≥4 days of data with ≥10 hours per day of accelerometer wear time.[21]

We used the following cut points for quantifying the duration of physical activity in different intensity levels: sedentary (<100 counts/min),[22] light (100-759 counts/min), lifestyle (760-2019 counts/min),[23] moderate (2020-5998 counts/min) and vigorous (≥5999 counts/min).[24] Counts/minute, minutes spent

sedentary, in light, lifestyle, moderate and moderate-to-vigorous physical activity per day as exposure variables were categorized into tertiles. Minutes spent in vigorous physical activity were only categorized into two groups (low=none, high=any) because 60% of the participants had no vigorous activities.

Self-reported physical activity was derived from the NHANES physical activity questionnaire. MET-minutes per week spent in different domains of physical activity (leisure-time, household, transport) were calculated and categorized into tertiles, except for transport activity which was dichotomized because 70% of participants reported no such activity. Minutes per week of moderate and vigorous activities were calculated. Because 64% of participants reported no vigorous activity, this variable was dichotomized into low (=none) and high (=any). For moderate activities, 44% reported no such activities, these were categorized as low. The remaining 56% were distributed evenly into the categories medium and high.

Overweight/obesity

DXA measurements

The whole body DXA scans were conducted using a Hologic QDR 4500A fan-beam densitometer (Hologic, Inc., Bedford, Massachusetts) following the manufacturer's acquisition procedures. Exclusion criteria during the examination were pregnancy and self-reported weight >136 kg or height >196 cm, exceeding the DXA table limits. The scan for each survey participant was reviewed, for details see the "Technical Documentation for the 1999-2004 Dual Energy X-Ray Absorptiometry (DXA) Multiple Imputation Data files (2008).[25]

A DXA scan provides multiple data points for each individual. The amount of missing DXA data was larger than for other type of data with indication of systematic, non-random patterns.[25] Because this could bias the results, users are provided with a "complete" data file, missing and invalid DXA data were imputed ("filling in plausible values for missing data") using multiple-imputation methodology. As a result, each survey participant gets five complete records containing valid (measured) and/or imputed values. For those with multiply imputed data, the five records consist of different sets of

imputed values. Participants with fully valid data have 5 identical records because no imputation was necessary, for details see [25].

Android (more "risky" central fat accumulation: "male" or "apple" shape) and gynoid (more "protective" peripheral fat accumulation: "female" or "pear" shape) fat distributions[26] were defined by the integrated Hologic APEX software. Percent total body fat derived from DXA measurement was categorized as normal weight (<25% for men, <35% for women) and overweight/obese (≥25% for men, ≥35% for women).[27]

Other measures of overweight and obesity

As secondary outcomes, BMI, WC, and WHtR were included. Weight was measured using a Toledo digital scale with the participants wearing underwear only.[28] Standing height was measured with a fixed stadiometer with a vertical backboard and a moveable headboard.[28] BMI was calculated as weight (in kg) divided by height squared (in meters) and categorized as normal weight (18.5-25 kg/m2), overweight (25-<30kg/m2), and obese (≥30 kg/m2).[29] WC was measured by trained health technicians in a standing position just above the uppermost lateral border of the ilium at the end of a normal expiration.[28] It was categorized as normal weight (<94 cm for men, <80 cm for women), overweight (94-<102cm/80-<88 cm), and obese (≥102 cm/≥88 cm).[29-31] Finally, WHtR was categorized as normal weight (<0.5), overweight (0.5-<0.6), and obese (≥0.6).[32,33]

Other variables

Socio-demographic variables (sex, age, race/ethnicity, education, marital status, and poverty income ratio [PIR]) and health-related variables (smoking status, alcohol intake, general health status, and mean energy intake) were included as potential confounders. Ethnicity was categorized as non-Hispanic White, non-Hispanic Black, Mexican-American, and other. Education was dichotomized into post-secondary education (college or higher) versus lower. Marital status was defined as living together versus single (including widowed, separated, divorced and never married). PIR was included as a measure of socio-economic status (at or above poverty versus below poverty).

Self-reported smoking behavior (current smoker versus current non-smoker), alcohol intake (no drinks, ≤1 drink per week, and >1 drink per week), sedentary behavior (mean minutes per day based on accelerometer data), and mean energy intake (kilo calories based on 24h recalls) were used as general healthy living indicators. Finally, general health status was included based on questionnaire data (excellent/very good, good, and not so good/poor). The dietary data to calculate total energy intake was based on the mean of two separate 24h recall interviews (if available, otherwise based on day 1), the first one conducted in-person during the MEC examination, the second one three to ten days later by telephone.

Statistical analyses

For descriptive statistics, weighted means and standard deviations for continuous variables and proportions for categorical variables are presented. For the DXA measures, the 5 sets of imputations were used according to the recommendations of NHANES[25] in order to correct for missing data, which are not at random. The five estimates were used to generate an overall mean, and combined standard errors were used to derive the overall 95% confidence intervals based on [25].

Ordered logistic regression models were used to model the association between different measures of physical activity and sedentary behavior on overweight/obesity as "ordered" outcome. Separate models were run for each physical activity variable with each overweight/obesity variable. Sex-specific tertiles of the physical activity and sedentary behavior variables were used as exposure with "low" as the reference category (versus medium and high). Because for vigorous and transport activities more than 50% of the participants had no such activities, we used only two categories (none, any). Linear regression analyses were used to investigate associations between continuous physical activity variables and percent body fat (total, android, gynoid, each as continuous variable in a separate model). These analyses were stratified by sex because of the sex-specific distribution (android = "male" or "apple" shape, gynoid = "female" or "pear" shape).

All analyses were adjusted for potential confounders (sociodemographic variables, health-related behavior). Additionally, the models that included a physical activity variable were adjusted for

sedentary behavior (but not for other physical activity variables due to collinearity), the models including sedentary behavior were adjusted for moderate-to-vigorous physical activity.

Four categories based on moderate-to-vigorous physical activity (MVPA, accelerometer) and sedentary behavior (accelerometer) were defined by splitting the two variables at their median: low MVPA/high sedentary time (reference), low MVPA/low sedentary time, high MVPA/high sedentary time, and high MVPA/low sedentary time. Associations of these variables with different measures of overweight and obesity were assessed using ordered logistic regression analyses.

All analyses were weighted according to the NHANES guidelines.[19] Statistical significance was set at $P<0.05$. The analyses were performed using STATA version 12 (Stata Corporation, College Station, TX, USA). Code availability: Please contact the corresponding author.

Results

Mean age of the study participants was 44.3 years and the proportion of women was 50.6%. Table 1 displays the characteristics of the participants by sex and body fat category. Overweight/obese men and women tended to be older compared to normal weight individuals, respectively.

Total, android and gynoid percent body fat and WHtR were significantly higher in women than men. WC was significantly higher in men (no significant sex difference for BMI). Men were more likely to be overweight according to BMI and WHtR, women according to percent body fat. Women were more likely than men to be obese according to WC and WHtR.

Physical activity levels tended to be lower in overweight/obese individuals and in women according to both objectively measured and self-reported instruments. Sedentary behavior was higher in overweight/obese individuals. Total energy intake was lower in women and overweight/obese individuals. Normal weight individuals and men more likely drank ≥1 alcoholic drink per week and smoked currently. Normal weight individuals more likely reported excellent health status compared to overweight individuals.

Table 2 shows the results of the ordered logistic regression analyses for categories of percent body fat, BMI, WC and WHtR associated with different objectively measured physical activity variables.

Statistically significant inverse associations were observed for mean counts/min, moderate, vigorous, and moderate-to-vigorous physical activity with all four overweight/obesity parameters. For example, the odds of being in a higher BMI category (i.e. overweight versus normal weight and obese versus overweight) was 0.64 (95% CI 0.50, 0.82) for individuals in the medium tertile and 0.40 (95% CI 0.30, 0.52) for those in the top tertile compared to those in the bottom tertile of moderate-to-vigorous physical activity. No associations were present for lifestyle activities, light activities and for sedentary behavior.

Table 3 shows the respective results for self-reported physical activity. Associations were most consistent for vigorous physical activity and for transport activities with all overweight/obesity outcomes. In addition, there were statistically significant associations between the top tertile of total (moderate-to-vigorous) physical activity and percent body fat, WC and WHtR, and between the top tertile of total leisure-time physical activity and percent body fat, WC and WHtR. For household physical activity, more physical activity was associated with higher odds of being in higher overweight/obesity categories. When including individuals with missing objectively measured physical activity in these analyses (sensitivity analysis), the results did not change substantially (for example, OR for being in a higher percent body fat category when in the highest tertile of total self-reported physical activity [compared to the lowest tertile]: OR=0.47 [95% CI 0.35, 0.62] for both samples in the fully adjusted model).

According to Supplementary Information Table 1 (linear regression models), there were statistically significant inverse associations between the objectively measured physical activity variables and percent total body fat such that more physical activity was associated with lower percentage of body fat. For example, total body fat was on average 0.21% (95% CI 0.17, 0.25) lower for each additional 100 MET-min/week of moderate-to-vigorous physical activity. In general, the associations were stronger for women than for men and slightly stronger for android than for gynoid fat areas. For light activities, the associations were significant for total and android fat in the non-stratified analyses. Unlike in the ordered logistic regression models (Table 2), there was an association between sedentary behavior and percent body fat (i.e., for each additional hour of sedentary time per day percent total body fat was on average 0.16% [95% CI 0.02, 0.30] higher); however, this association was only

present for total body fat but not for android or gynoid fat or stratified by sex. For self-reported physical activity, the associations were generally weaker and consistently statistically significant only for total leisure-time physical activity and for vigorous physical activity.

Figure 1 shows the associations between the four categories of low and high objectively measured moderate-to-vigorous physical activity/sedentary behavior and different measures of overweight/obesity. The distribution of participants in the four categories was 29.7% for low MVPA/high sedentary time, 20.6% for low MVPA/low sedentary time, 20.3% for high MVPA/high sedentary time and 29.4% for high MVPA/low sedentary time. The odds of being in a higher category of percent body fat, BMI, WC and WHtR were statistically significantly lower for individuals with high objectively measured moderate-to-vigorous physical activity independent of sedentary behavior, whereas low compared to high sedentary time was not significantly associated with body weight status.

Discussion

We observed statistically significant associations between objectively measured moderate, vigorous and total physical activity and all measures of overweight/obesity (BMI, percent body fat based on DXA measures, WC, and WHtR). Associations for light and lifestyle physical activity and for sedentary behavior were weak or non-significant and were only observed in the non-stratified linear models. Regarding self-reported physical activity, consistent significant associations with all overweight/obesity variables were observed for vigorous physical activity and transport activity (ordered logistic regression), and for total and vigorous physical activity (linear regression). When looking at the combined association of moderate-to-vigorous physical activity and sedentary behavior (Figure 1), it seems that sedentary behavior is not associated with overweight/obesity independent of the physical activity category supporting our null findings for sedentary behavior in Table 2.

For objectively measured physical activity, we observed consistent associations with overweight/obesity both for moderate and vigorous physical activity, but for self-reported physical activity associations were only present for vigorous but not for moderate activities. One possible

explanation is that the intensity of the activity was overestimated and, thus, self-reported moderate physical activity corresponds better with accelerometer-derived light activities. This is supported by a validation study, which indeed indicated that self-reported moderate activities correlate better with objectively measured light than with moderate activities.[34] In addition, the fact that objectively measured physical activity was more consistently associated with overweight/obesity than self-reported physical activity indicates that the latter may be more prone to misclassification, especially regarding moderate physical activity and household tasks. On the other hand, the advantage of the self-reported physical activity data is that information regarding domains (leisure-time, transport, household) is available.

Regarding overweight/obesity, the associations were generally strongest for the objective assessment of body composition (DXA based) and weakest for BMI. For example, self-reported physical activity associations were more consistent for percent body fat and for WHtR than for BMI and WC (Table 3). Similar results have been reported in a Swiss study on self-reported physical activity based on the International Physical Activity Questionnaire IPAQ and different measures of overweight and obesity.[35] A reason may be that percent body fat and WHtR are more appropriate measures to define overweight/obesity than, for example, BMI, and that associations become diluted if measurement error in self-reported physical activity is present. For example, BMI is influenced by body fat mass, but also by muscle mass, which are both associated with physical activity.[36]

Based on linear regression models (Supplementary Information Table 1), the strength of association between physical activity and percent body fat decreases with decreasing intensity, indicating that higher intensity activities may be more effective in weight management, even though it seems that also lower-intensity activities have at least some small effect. Similarly, but also taking into account duration in addition to intensity, a dose-response association between total amounts of self-reported leisure-time physical activity and obesity has been reported in adult women, but not in men.[37] In our study, the effect sizes were generally slightly stronger for android than for gynoid fat (Supplementary Information Table 1) and for women compared to men.

The results of other studies investigating the associations between objectively measured physical activity and sedentary time with overweight/obesity were mixed. Based on NHANES data from 2003-

04, Strath et al. reported associations both for bout and non-bout moderate-to-vigorous physical activity with BMI and WC, with stronger effects for activity performed in bouts of at least 10 minutes.[15] Even though in our analyses adjustment for sedentary behavior did not change the direction of the results, it has to be mentioned that the analyses by Strath et al. were not adjusted for sedentary behavior and for diet. Healy et al. focused on the effect of sedentary time and breaks in sedentary time (based on accelerometry) on WC (among other biomarkers) using NHANES data from 2003-2006.[16] Using linear regression models and physical activity and dietary variables as confounders, the authors reported statistically significant associations between sedentary time, breaks in sedentary time and WC. However, when stratifying the analyses by race/ethnicity, the results for sedentary behavior were only statistically significant in the expected direction for non-Hispanic Whites, with null effects for Mexican Americans and effects in the other than expected direction for non-Hispanic Blacks. Again, using NHANES data from 2003-2006, Maher and colleagues investigated the associations between physical activity and sedentary time and obesity based on BMI.[17] Similar to our results, the authors concluded that physical activity was strongly associated with BMI regardless of sedentary time, whereas no significant results were reported for sedentary time. A number of reports have been published based on the Health Survey for England[12-14] showing that objectively measured physical activity was associated with BMI,[14] while there were no associations between objectively measured sedentary time and WC or BMI in working-age adults[13] and only with WC but not BMI in older adults.[12] This is again in line with our results.

Regarding associations between different domains of physical activity and overweight/obesity, most other studies reported no favorable (inverse) association for domestic physical activity,[38,39] which is in line with our results. This may be due to residual confounding or larger reporting bias as individuals may be likely to over-report intensity and/or duration of domestic activities compared to e.g. leisure-time activities. An inverse relationship between transport physical activity and overweight/obesity has also been reported in a systematic review,[40] and evidence regarding an association between leisure-time physical activity and weight status is also available.[18]

Like most others, this is a cross-sectional study and no causal inference is possible. It is commonly assumed that physical activity is a determinant of body fat due to energy expenditure.[41] However,

more recent research suggests that obesity is a determinant of physical activity rather than the other way around, in that baseline body fat predicted follow-up physical activity.[41] On the other hand, physical activity patterns over a ten year period (remaining inactive versus remaining active) were significantly associated with obesity at follow-up in a recent study.[35] A similar discussion regarding reverse causality is ongoing for sedentary behavior. Research based on large longitudinal studies has pointed out that obesity is a predictor of self-reported sitting time while associations in the other direction were unclear or not significant.[42-44] It is therefore possible that significant associations between sedentary time and overweight/obesity in cross-sectional studies (see e.g. Healy et al. (2011)[16]) are attributable to reverse causality. More research is needed to disentangle the longitudinal associations between physical activity, sedentary behavior and overweight/obesity ideally using objective measurements.

The strengths of this study are the large and US nationally representative sample, the use of objectively measured data for physical activity, sedentary behavior and body composition, the use of self-reported physical activity data regarding domains, and the inclusion of a variety of potential confounders including socio-demographic variables, health-related variables and diet. Limitations of the study are its cross-sectional design and thus the possibility of reverse causality (overweight and obese people may be less likely to be active due to their body mass), the fact that accelerometers had to be taken off during water-based activities and that some activities are not measured well using uni-axial accelerometer data, such as bicycling. This could result in an underestimation of physical activity. Accelerometer wear time that is smaller than mean time awake may be another issue, however mean wear time was >14 hours and was therefore relatively high. There is also a limitation of accelerometers in assessing sedentary behavior. Even though we have adjusted for a number of covariates, we cannot rule out the possibility of residual confounding. Regarding self-reported physical activity, recall bias may be a problem.

In conclusion, objectively measured physical activity was associated with all overweight/obesity variables, emphasizing the public health effect of physical activity in the prevention of overweight/obesity. Associations between lower intensity activities and overweight/obesity were weak

or inexistent. More research is needed to disentangle the longitudinal associations between physical activity, sedentary behavior and overweight/obesity ideally using objective measurements.

Conflict of interest

The authors declare no conflict of interest.

Supplementary information is available at the International Journal of Obesity's website

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488

Table 1. Characteristics of participants, by sex and weight status according to percent body fat, NHANES 2003-06

	Males		Females	
	normal weight (<25% body fat)	overweight/obese (≥25% body fat)	normal weight (<35% body fat)	overweight/obese (≥35% body fat)
N (unweighted)	771	1689	509	1825
Proportion [%]	16.3	35.2	10.6	38.1
Age [years], mean (SE)	37.4 (0.7)	45.9 (0.5)	38.7 (0.6)	46.9 (0.5)
Ethnicity [%]				
Non-Hispanic White	69.9	75.8	75.6	73.0
Non-Hispanic Black	13.6	8.1	7.6	11.5
Mexican American	7.6	9.5	6.3	7.6
Other	8.9	6.6	10.5	7.9
Marital status [%]				
Married/living together	61.0	73.5	61.4	65.6
Single (widowed, separated, divorced)	39.0	26.3	38.3	34.4
Missing information	0.0	0.2	0.3	0.0
Poverty index ratio [%]				
Below poverty	10.8	7.7	9.2	8.9
At or above poverty	85.6	88.8	87.4	87.7
Missing information	3.6	3.5	3.4	3.4
Education [%]				
High school or lower	32.8	39.3	24.5	38.6
Post secondary (college or higher)	61.4	59.4	70.3	59.7
Missing information	5.8	1.3	5.1	1.7
Total body fat [%], mean (SE)	21.0 (0.2)	30.8 (0.2)	30.9 (0.2)	42.7 (0.2)
Android body fat [%], mean (SE)	21.7 (0.3)	35.8 (0.2)	27.2 (0.4)	42.2 (0.2)
Gynoid body fat [%], mean (SE)	21.8 (0.2)	29.8 (0.2)	36.1 (0.3)	44.2 (0.2)
Body Mass Index [kg/m^2], mean (SE)	23.8 (0.1)	30.0 (0.2)	21.9 (0.1)	30.4 (0.3)
Waist circumference [cm], mean (SE)	86.5 (0.5)	106.0 (0.5)	78.3 (0.3)	98.5 (0.6)
Waist-to-height ratio, mean (SE)	0.49 (0.003)	0.60 (0.003)	0.48 (0.002)	0.61 (0.004)
BMI category [%]				
Normal/underweight	68.3	10.8	92.5	22.0
Overweight	29.9	46.2	7.4	34.8
Obese	1.5	42.7	0.1	42.7
Missing information	0.3	0.4	0.0	0.4

Waist circumference category [%]				
Normal weight	82.8	14.0	62.4	7.4
Overweight	13.2	26.4	30.1	16.1
Obese	2.7	57.8	6.3	75.7
Missing information	1.4	1.8	1.3	0.8
Waist-to-height ratio category [%]				
Normal weight	60.8	3.8	71.9	8.2
Overweight	37.4	51.9	26.2	46.0
Obese	0.2	42.5	0.6	45.0
Missing information	1.6	1.8	1.3	0.8
Objectively measured physical activity, mean (SE)				
Wear time [hours/day]	14.6 (0.09)	14.5 (0.06)	14.2 (0.11)	14.2 (0.06)
Mean total [counts/min]	425 (6)	346 (5)	361 (7)	290 (4)
Moderate and vigorous [min/d]	42.0 (1.2)	28.2 (0.8)	27.5 (1.3)	16.7 (0.6)
Self-reported physical activity, mean (SE)				
Total leisure-time [min/d]	326.2 (27.7)	200.8 (9.3)	267.1 (20.2)	147.2 (7.2)
Moderate leisure-time [min/d]	199.7 (27.2)	142.9 (7.8)	148.3 (14.5)	103.2 (5.3)
Vigorous leisure-time [min/d]	126.5 (12.9)	57.8 (5.0)	118.8 (13.2)	44.0 (3.7)
Objectively measured sedentary behavior [hours/day]	7.8 (0.08)	8.2 (0.07)	7.7 (0.11)	8.0 (0.06)
Total energy intake [kcal], mean (SE)	2792 (42)	2539 (27)	1914 (44)	1790 (17)
Smoking status [%]				
Current non-smoker	68.5	76.6	74.3	82.4
Current smoker	31.5	23.4	25.7	17.6
Alcohol intake [%]				
No drinks	30.6	26.8	28.9	36.0
≤1 drink/week	19.9	30.1	36.4	42.0
>1 drink/week	49.5	43.1	34.7	22.0
Health status [%]				
Excellent or very good	57.4	46.1	65.3	42.5
Good	30.3	37.1	22.0	38.6
Not so good or bad	8.2	13.8	9.2	14.8
Missing information	4.2	3.0	3.4	4.1

Note: analyses weighted according to the NHANES guidelines (16)

493 **Table 2. Associations between different intensities of objectively measured physical activity, sitting time and body weight (ordered logistic regressions)**

	cut points for categories men	cut points for categories women	% body fat		BMI		WC		WHtR	
			OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Mean total activity (counts/min)										
low	<287.8	<242.3	1.00		1.00		1.00		1.00	
medium	287.8-424.85	242.3-332.90	0.65	0.46, 0.90	0.71	0.58, 0.86	0.61	0.48, 0.78	0.64	0.51, 0.81
high	>424.85	>332.90	0.33	0.24, 0.45	0.48	0.37, 0.62	0.44	0.34, 0.58	0.46	0.36, 0.59
p for trend				<0.001		<0.001		<0.001		<0.001
Total (moderate-to-vigorous) physical activity (MET-min/week)										
low	<509.0	<229.6	1.00		1.00		1.00		1.00	
medium	509.1-1120.0	229.6-612	0.56	0.41, 0.77	0.64	0.50, 0.82	0.53	0.44, 0.64	0.57	0.44, 0.74
high	>1120.0	>612	0.30	0.22, 0.40	0.40	0.30, 0.52	0.37	0.29, 0.48	0.39	0.31, 0.49
p for trend				<0.001		<0.001		<0.001		<0.001
Vigorous physical activity (min/day)										
none	0	0	1.00		1.00		1.00		1.00	
any	>0	>0	0.53	0.42, 0.67	0.65	0.54, 0.78	0.64	0.53, 0.77	0.60	0.50, 0.73
Moderate physical activity (min/day)										
low	<17.6	<8.15	1.00		1.00		1.00		1.00	
medium	17.6-37.3	8.15-21.0	0.58	0.42, 0.79	0.64	0.50, 0.80	0.54	0.45, 0.65	0.57	0.44, 0.72
high	>37.3	>21.0	0.32	0.24, 0.44	0.41	0.32, 0.54	0.41	0.33, 0.51	0.42	0.33, 0.53
p for trend				<0.001		<0.001		<0.001		<0.001
Lifestyle physical activity (min/day)										
low	<75.2	<61.72	1.00		1.00		1.00		1.00	
medium	75.2-120.5	61.72-94.17	1.07	0.84, 1.36	0.97	0.84, 1.12	0.92	0.75, 1.12	0.91	0.74, 1.12

high	>120.5		0.80	0.60, 1.07	0.93	0.73, 1.19	0.84	0.64, 1.11	0.85	0.66, 1.10
p for trend				0.057		0.837		0.465		0.455
Light activities (min/day)										
low	<227.2	<244.4	1.00		1.00		1.00		1.00	
medium	227.2-283.0	244.5-297.84	0.91	0.70, 1.19	1.02	0.84, 1.25	0.89	0.71, 1.12	0.87	0.70, 1.09
high	>283.0	>297.84	0.98	0.74, 1.32	1.14	0.92, 1.41	0.97	0.76, 1.24	0.88	0.73, 1.05
p for trend				0.736		0.443		0.569		0.318
Sitting time (min/day)										
low	<420.1	<427.6	1.00		1.00		1.00		1.00	
medium	420.1-527.6	427.6-519.1	1.13	0.86, 1.47	0.94	0.77, 1.14	0.93	0.72, 1.18	0.99	0.81, 1.22
high	>527.6	>519.1	1.17	0.92, 1.49	1.04	0.87, 1.23	1.13	0.87, 1.48	1.18	0.94, 1.47
p for trend				0.445		0.463		0.162		0.113

Note: all models were adjusted for sex, age, ethnicity, PIR, education, marital status, alcohol intake, smoking status, general health, mean energy intake, sitting time (for models on physical activity) and moderate-to-vigorous physical activity (models on sitting time), respectively.

Interpretation of OR: The odds of being in a higher overweight/obesity category if being in a higher physical activity tertile. For example, the odds of being in a higher BMI category (i.e. overweight versus normal weight and obese versus overweight) was 0.64 (95% CI 0.50, 0.82) for individuals in the medium tertile and 0.40 (95% CI 0.30, 0.52) for those in the top tertile compared to those in the bottom tertile of moderate-to-vigorous physical activity.

502 **Table 3. Associations between different domains and intensities of self-reported physical activity and body weight (ordered logistic regressions)**

	cut points for categories men	cut points for categories women	% body fat		BMI		WC		WHtR	
			OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Total (moderate-to-vigorous) physical activity (MET-min/week)										
low	<482.6	<368.0	1.00		1.00		1.00		1.00	
medium	482.6-1882	368.0-1510.5	0.86	0.59, 1.25	0.98	0.75, 1.28	0.94	0.72, 1.22	0.83	0.63, 1.08
high	>1882	>1510.5	0.47	0.35, 0.62	0.82	0.62, 1.10	0.69	0.54, 0.88	0.68	0.51, 0.92
p for trend				<0.001		0.174		0.007		0.040
Total vigorous physical activity (min/week)*										
none	0	0	1.00		1.00		1.00		1.00	
any	>0	>0	0.49	0.39, 0.60	0.73	0.61, 0.87	0.61	0.51, 0.74	0.64	0.52, 0.79
Total moderate physical activity (min/week)										
low	<61.0	<65.0	1.00		1.00		1.00		1.00	
medium	61.0-300.3	65.0-243.54	1.10	0.81, 1.49	1.09	0.84, 1.41	1.06	0.83, 1.35	1.04	0.79, 1.36
high	>300.3	>243.54	0.76	0.56, 1.02	1.04	0.77, 1.40	0.93	0.69, 1.26	0.89	0.64, 1.24
p for trend				0.038		0.741		0.405		0.417
Total (moderate-to-vigorous) leisure-time physical activity (MET-min/week)										
low	<14	0	1.00		1.00		1.00		1.00	
medium	14-1000	1-717.5	0.87	0.65, 1.16	1.10	0.87, 1.38	1.06	0.87, 1.30	1.01	0.84, 1.23
high	>1000	>717.5	0.56	0.42, 0.75	0.84	0.66, 1.08	0.77	0.60, 0.98	0.72	0.58, 0.89
p for trend				<0.001		0.082		0.021		0.012
Moderate leisure-time physical activity (min/week)										
low	0	0	1.00		1.00		1.00		1.00	
medium	1-145.5	1-110.8	0.94	0.73, 1.21	1.14	0.92, 1.42	1.08	0.90, 1.29	1.04	0.88, 1.23
high	>145.5	>110.8	0.77	0.59, 1.01	1.03	0.83, 1.28	0.98	0.78, 1.23	0.88	0.70, 1.10

p for trend				0.160		0.444		0.578		0.468
Transport physical activity (MET-min/week)										
none	0	0	1.00		1.00		1.00		1.00	
any	>0	>0	0.78	0.64, 0.94	0.74	0.60, 0.91	0.77	0.64, 0.92	0.78	0.63, 0.96
Household physical activity (MET-min/week)										
low	<5	0	1.00		1.00		1.00		1.00	
medium	5-380	1-380	1.30	1.03, 1.64	1.28	1.05, 1.57	1.35	1.11, 1.64	1.31	1.08, 1.59
high	>380	>380	1.13	0.86, 1.49	1.50	1.20, 1.88	1.43	1.11, 1.84	1.35	1.07, 1.70
p for trend				0.070		0.004		0.008		0.020

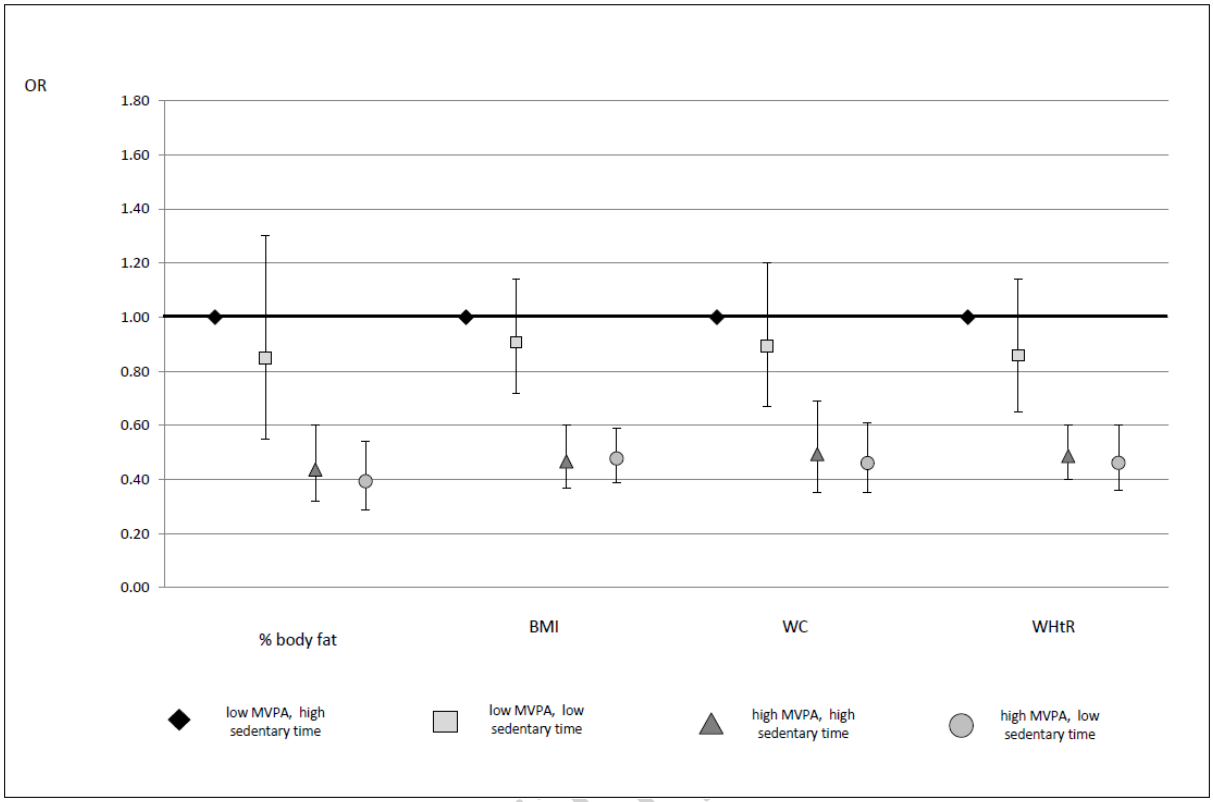
*total vigorous physical activity is equal to leisure-time vigorous physical activity, as only the domain leisure-time includes vigorous activities

Note: all models were adjusted for sex, age, ethnicity, PIR, education, marital status, alcohol intake, smoking status, general health, mean energy intake, sitting time. Models on transport and household physical activity were adjusted for total leisure-time physical activity in addition.

Interpretation of OR: The odds of being in a higher overweight/obesity category if being in a higher physical activity tertile. For example, the odds of being in a higher BMI category (i.e. overweight versus normal weight and obese versus overweight) was 0.98 (95% CI 0.75, 1.28) for individuals in the medium tertile and 0.82 (95% CI 0.62, 1.10) for those in the top tertile compared to those in the bottom tertile of total moderate-to-vigorous physical activity.

513 **Figure 1. Associations between categories of low/high physical activity/sedentary behavior and**

514 **different measures of overweight/obesity**



515

516 Abbreviations: BMI, body mass index; MVPA, moderate-to-vigorous physical activity; OR, odds ratio; WC, waist

517 circumference; WHtR, waist-to-height ratio

Supplementary Information Table 1. Associations between objective and self-reported physical activity and percent body fat (total, android, gynoid) based on linear regression, by sex, NHANES 2003-06

	% total body fat		% body fat (android)						% body fat (gynoid)					
	Total		Total		Men		Women		Total		Men		Women	
	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI	beta	95% CI
Objective physical activity														
Mean total PA (10 counts/min)	-0.119	-0.139, -0.098	-0.143	-0.173, -0.113	-0.098	-0.127, -0.068	-0.204	-0.266, -0.143	-0.106	-0.127, -0.084	-0.090	-0.109, -0.071	-0.127	-0.164, -0.089
Total MVPA (100 MET-min/week)	-0.211	-0.247, -0.174	-0.246	-0.300, -0.192	-0.157	-0.206, -0.108	-0.400	-0.537, -0.262	-0.188	-0.223, -0.152	-0.145	-0.178, -0.112	-0.266	-0.342, -0.189
Vigorous PA (10 min/day)	-2.454	-3.124, -1.784	-3.111	-4.297, -1.924	-1.753	-3.270, -0.237	-4.797	-6.629, -2.965	-2.053	-2.594, -1.511	-1.282	-1.930, -0.634	-3.073	-4.372, -1.775
Moderate PA (10 min/day)	-0.596	-0.718, -0.474	-0.675	-0.850, -0.499	-0.460	-0.620, -0.299	-1.055	-1.489, -0.621	-0.542	-0.668, -0.416	-0.450	-0.567, -0.333	-0.712	-0.991, -0.434
Lifestyle PA (10 min/day)	-0.156	-0.207, -0.104	-0.225	-0.327, -0.124	-0.201	-0.302, -0.099	-0.263	-0.416, -0.111	-0.161	-0.215, -0.107	-0.199	-0.268, -0.130	-0.111	-0.185, -0.036
Light PA (10 min/day)	-0.046	-0.085, -0.006	-0.080	-0.156, -0.004	-0.097	-0.208, 0.014	-0.049	-0.168, 0.070	-0.037	-0.096, 0.023	-0.053	-0.134, 0.028	-0.019	-0.098, 0.061
Mean sedentary time (1 hour/day)	0.159	0.019, 0.299	0.101	-0.120, 0.321	0.082	-0.182, 0.346	0.121	-0.174, 0.416	0.074	-0.068, 0.216	0.062	-0.114, 0.239	0.098	-0.116, 0.312
Self-reported physical activity														
Total PA (100 MET-min/week)	-0.021	-0.034, -0.009	-0.025	-0.047, -0.003	-0.015	-0.039, 0.008	-0.041	-0.068, -0.015	-0.023	-0.039, -0.007	-0.016	-0.034, 0.001	-0.035	-0.053, -0.016
Total vigorous PA (10 min/day)*	-0.406	-0.518, -0.294	-0.524	-0.759, -0.289	-0.391	-0.652, -0.131	-0.661	-0.926, -0.397	-0.421	-0.538, -0.303	-0.337	-0.472, -0.202	-0.515	-0.677, -0.352
Total moderate PA (10 min/day)	-0.023	-0.062, 0.015	-0.019	-0.085, 0.048	0.0002	-0.079, 0.080	-0.064	-0.148, 0.020	-0.027	-0.082, 0.028	-0.015	-0.075, 0.046	-0.057	-0.127, 0.012
Total (MVPA) LTPA (100 MET-min/week)	-0.044	-0.060, -0.028	-0.056	-0.084, -0.028	-0.033	-0.064, -0.001	-0.093	-0.125, -0.061	-0.045	-0.064, -0.027	-0.034	-0.055, -0.013	-0.064	-0.087, -0.040
Moderate LTPA (10 min/day)	-0.048	-0.129, 0.032	-0.056	-0.183, 0.071	0.004	-0.140, 0.147	-0.203	-0.358, -0.048	-0.050	-0.145, 0.045	-0.033	-0.130, 0.064	-0.092	-0.244, 0.059
Transport PA (100 MET-min/week)	-0.021	-0.048, 0.006	-0.037	-0.099, 0.026	-0.033	-0.114, 0.049	-0.081	-0.169, 0.007	-0.030	-0.072, 0.012	-0.026	-0.077, 0.025	-0.059	-0.140, 0.022
Household PA (100 MET-min/week)	0.007	-0.007, 0.020	0.016	-0.007, 0.039	0.014	-0.012, 0.039	0.017	-0.017, 0.052	0.006	-0.011, 0.024	0.011	-0.007, 0.029	-0.002	-0.028, 0.024

*total vigorous physical activity is equal to leisure-time vigorous physical activity, as only the domain leisure-time includes vigorous activities

Note: all models were adjusted for sex, age, ethnicity, PIR, education, marital status, alcohol intake, smoking status, general health, mean energy intake, sitting time based on accelerometer data (for models on physical activity) and moderate-to-vigorous physical activity (models with sedentary time), respectively. LTPA, leisure-time physical activity; MET, metabolic equivalent; MVPA, moderate-to-vigorous physical activity; PA, physical activity